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(54) **SYSTEMS AND METHODS FOR OBTAINING LARGE CREEPAGE ISOLATION ON PRINTED CIRCUIT BOARDS**

(75) Inventor: **Dejan Teofilovic**, Ann Arbor, MI (US)

(73) Assignee: **HISTOSONICS, INC.**, Ann Arbor, MI (US)

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CPC ***H05K 1/0256*** (2013.01); *H05K 2201/09972* (2013.01); *H05K 2201/10121* (2013.01)

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See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,243,497	A		3/1966	Kendall et al.
3,679,021	A		7/1972	Goldberg
4,024,501	A		5/1977	Herring et al.
4,051,394	A	*	9/1977	Tieden 327/79
4,117,446	A		9/1978	Alais
4,269,174	A		5/1981	Adair
4,277,367	A		7/1981	Madsen et al.
4,351,038	A		9/1982	Alais
4,406,153	A		9/1983	Ophir et al.
4,440,025	A		4/1984	Hayakawa et al.
4,453,408	A		6/1984	Clayman
4,483,345	A		11/1984	Miwa

(Continued)

FOREIGN PATENT DOCUMENTS

DE	3220751	A1	12/1983
DE	3544628	A1	6/1987

(Continued)

OTHER PUBLICATIONS

Bjoerk et al.; Cool/MOS CP—How to make most beneficial use of the generation of super junction technology devices. Infineon Technologies AG. Feb. 2007 [retrieved Feb. 4, 2014] from the internet (http://www.infineon.com/dgdl/Infineon+- +-+Application+ Note+-+PowerMOSFETs+-+600V+CoolMOS%E284%A2+-+CP+ Most+ beneficial+use+of+superjunction+technologie+devices. pdf?folderId=db3a304412b407950112b408e8c90004 &fileId=db3a304412b407950112b40ac9a40688>pp. 1, 4, 14.

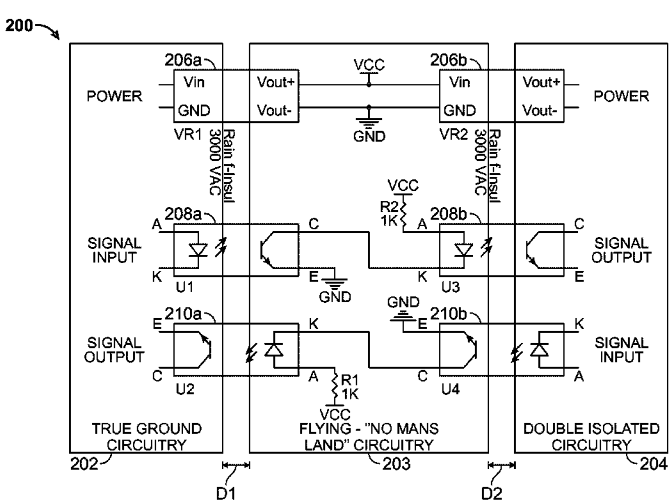
(Continued)

Primary Examiner — Emily P Pham
(74) *Attorney, Agent, or Firm* — Shay Glenn LLP

(57) **ABSTRACT**

An electrical circuit with large creepage isolation distances is provided. In some embodiments, the electrical circuit is capable of increasing creepage isolation distances by many multiples over traditional electrical circuits. In one embodiment, an electrical circuit comprises a ground circuit optically coupled to a floating circuit, and an isolated circuit optically coupled to the floating circuit. The circuits can be optically coupled with opto-isolators, for example. The isolated circuit can have a creepage isolation distance at least twice as large as a traditional circuit. In some embodiments, "n" number of floating circuits can be optically coupled between the ground circuit and the isolated circuit to increase the total creepage isolation distance by a factor of "n". Methods of use are also described.

24 Claims, 5 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

4,549,533 A 10/1985 Cain et al.
4,550,606 A 11/1985 Drost
4,575,330 A 3/1986 Hull
4,622,972 A 11/1986 Giebeler, Jr.
4,625,731 A 12/1986 Quedens et al.
4,641,378 A 2/1987 McConnell et al.
4,669,483 A 6/1987 Hepp et al.
4,689,986 A 9/1987 Carson et al.
4,757,820 A 7/1988 Itoh
4,791,915 A 12/1988 Barsotti et al.
4,819,621 A 4/1989 Ueberle et al.
4,829,491 A 5/1989 Saugeon et al.
4,856,107 A 8/1989 Dory
4,865,042 A 9/1989 Umemura et al.
4,888,746 A 12/1989 Wurster et al.
4,890,267 A 12/1989 Rudolph
4,922,917 A 5/1990 Dory
4,938,217 A 7/1990 Lele
4,957,099 A 9/1990 Hassler
4,973,980 A 11/1990 Howkins et al.
4,984,575 A 1/1991 Uchiyama et al.
4,991,151 A 2/1991 Dory
4,995,012 A 2/1991 Dory
RE33,590 E 5/1991 Dory
5,014,686 A 5/1991 Schafer
5,065,751 A 11/1991 Wolf
5,080,101 A 1/1992 Dory
5,080,102 A 1/1992 Dory
5,091,893 A 2/1992 Smith et al.
5,092,336 A 3/1992 Fink
5,097,709 A 3/1992 Masuzawa et al.
5,111,822 A 5/1992 Dory
5,143,073 A 9/1992 Dory
5,143,074 A 9/1992 Dory
5,150,711 A 9/1992 Dory
5,158,070 A 10/1992 Dory
5,158,071 A 10/1992 Umemura et al.
5,163,421 A 11/1992 Bernstein et al.
5,209,221 A 5/1993 Riedlinger
5,215,680 A 6/1993 D'Arrigo
5,219,401 A 6/1993 Cathignol et al.
5,230,340 A 7/1993 Rhyne
5,295,484 A 3/1994 Marcus et al.
5,316,000 A 5/1994 Chapelon et al.
5,354,258 A 10/1994 Dory
5,380,411 A 1/1995 Schlief
5,409,002 A 4/1995 Pell
5,431,621 A 7/1995 Dory
5,435,311 A 7/1995 Umemura et al.
5,443,069 A 8/1995 Schaetzle
5,469,852 A 11/1995 Nakamura et al.
5,474,071 A 12/1995 Chapelon et al.
5,474,531 A 12/1995 Carter
5,501,655 A 3/1996 Rolt et al.
5,520,188 A 5/1996 Hennige et al.
5,523,058 A 6/1996 Umemura et al.
5,524,620 A 6/1996 Rosenschein
5,540,909 A 7/1996 Schutt
5,542,935 A 8/1996 Unger et al.
5,558,092 A 9/1996 Unger et al.
5,563,346 A 10/1996 Bartelt et al.
5,566,675 A 10/1996 Li et al.
5,573,497 A 11/1996 Chapelon
5,580,575 A 12/1996 Unger et al.
5,582,578 A 12/1996 Zhong et al.
5,590,657 A 1/1997 Cain et al.
5,601,526 A 2/1997 Chapelon et al.
5,617,862 A 4/1997 Cole et al.
5,648,098 A 7/1997 Porter
5,666,954 A 9/1997 Chapelon et al.
5,676,452 A 10/1997 Scholz
5,676,692 A 10/1997 Sanghvi et al.
5,678,554 A 10/1997 Hossack et al.
5,694,936 A 12/1997 Fujimoto et al.
5,695,460 A 12/1997 Siegel et al.
5,717,657 A 2/1998 Ruffa
5,724,972 A 3/1998 Petrofsky
5,743,863 A 4/1998 Chapelon
5,753,929 A * 5/1998 Bliss 250/551
5,759,162 A 6/1998 Oppelt et al.
5,766,138 A 6/1998 Rattner
5,769,790 A 6/1998 Watkins et al.
5,797,848 A 8/1998 Marian et al.
5,823,962 A 10/1998 Schaetzle et al.
5,827,204 A 10/1998 Grandia et al.
5,836,896 A 11/1998 Rosenschein
5,849,727 A 12/1998 Porter et al.
5,873,902 A 2/1999 Sanghvi et al.
5,879,314 A 3/1999 Peterson et al.
5,932,807 A 8/1999 Mallart
5,947,904 A 9/1999 Hossack et al.
6,001,069 A 12/1999 Tachibana et al.
6,022,309 A 2/2000 Celliers et al.
6,036,667 A 3/2000 Manna et al.
6,088,613 A 7/2000 Unger
6,093,883 A 7/2000 Sanghvi et al.
6,113,558 A 9/2000 Rosenschein et al.
6,126,607 A 10/2000 Whitmore, III et al.
6,128,958 A 10/2000 Cain
6,143,018 A 11/2000 Beuthan et al.
6,176,842 B1 1/2001 Tachibana et al.
6,308,585 B1 10/2001 Nilsson et al.
6,308,710 B1 10/2001 Silva
6,309,355 B1 10/2001 Cain et al.
6,318,146 B1 11/2001 Madsen et al.
6,321,109 B2 11/2001 Ben-Haim et al.
6,338,566 B1 1/2002 Verdier
6,344,489 B1 2/2002 Spears
6,391,020 B1 5/2002 Kurtz et al.
6,413,216 B1 7/2002 Cain et al.
6,419,648 B1 7/2002 Vitek et al.
6,470,204 B1 10/2002 Uzgiris et al.
6,488,639 B1 12/2002 Ribault et al.
6,490,469 B2 12/2002 Candy
6,500,141 B1 12/2002 Irion et al.
6,506,154 B1 1/2003 Ezion et al.
6,506,171 B1 1/2003 Vitek et al.
6,508,774 B1 1/2003 Acker et al.
6,511,428 B1 1/2003 Azuma et al.
6,511,444 B2 1/2003 Hynynen et al.
6,522,142 B1 2/2003 Freundlich
6,524,251 B2 2/2003 Rabiner et al.
6,543,272 B1 4/2003 Vitek
6,556,750 B2 * 4/2003 Constantino et al. 385/41
6,559,644 B2 5/2003 Froundlich et al.
6,576,220 B2 6/2003 Unger
6,599,288 B2 7/2003 Maguire et al.
6,607,498 B2 8/2003 Eshel
6,612,988 B2 9/2003 Maor et al.
6,613,004 B1 9/2003 Vitek et al.
6,613,005 B1 9/2003 Friedman et al.
6,626,854 B2 9/2003 Friedman et al.
6,626,855 B1 9/2003 Weng et al.
6,645,162 B2 11/2003 Friedman et al.
6,648,839 B2 11/2003 Manna et al.
6,666,833 B1 12/2003 Friedman et al.
6,685,640 B1 2/2004 Fry et al.
6,685,657 B2 2/2004 Jones
6,705,994 B2 3/2004 Vortman et al.
6,719,449 B1 4/2004 Laugharn, Jr. et al.
6,719,694 B2 4/2004 Weng et al.
6,735,461 B2 5/2004 Vitek et al.
6,736,814 B2 5/2004 Manna et al.
6,750,463 B1 * 6/2004 Riley 250/551
6,770,031 B2 8/2004 Hynynen et al.
6,775,438 B1 * 8/2004 Gaedke et al. 385/42
6,788,977 B2 9/2004 Fenn et al.
6,790,180 B2 9/2004 Vitek
6,820,160 B1 * 11/2004 Allman 710/305
6,852,082 B2 2/2005 Strickberger et al.
6,869,439 B2 3/2005 White et al.
6,890,332 B2 5/2005 Truckai et al.
6,929,609 B2 8/2005 Asafusa
7,004,282 B2 2/2006 Manna et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

7,059,168	B2	6/2006	Hibi et al.	
7,128,711	B2	10/2006	Medan et al.	
7,128,719	B2	10/2006	Rosenberg	
7,175,596	B2	2/2007	Vitek et al.	
7,196,313	B2 *	3/2007	Quinones et al.	250/214.1
7,223,239	B2	5/2007	Schulze et al.	
7,258,674	B2	8/2007	Cribbs et al.	
7,273,458	B2	9/2007	Prausnitz et al.	
7,273,459	B2	9/2007	Desilets et al.	
7,300,414	B1	11/2007	Holland et al.	
7,311,679	B2	12/2007	Desilets et al.	
7,331,951	B2	2/2008	Eshel et al.	
7,341,569	B2	3/2008	Soltani et al.	
7,347,855	B2	3/2008	Eshel et al.	
7,358,226	B2	4/2008	Dayton et al.	
7,359,640	B2 *	4/2008	Onde et al.	398/135
7,367,948	B2	5/2008	O'Donnell et al.	
7,374,551	B2	5/2008	Liang et al.	
7,377,900	B2	5/2008	Vitek et al.	
7,442,168	B2	10/2008	Novak et al.	
7,462,488	B2	12/2008	Madsen et al.	
7,559,905	B2	7/2009	Kagosaki et al.	
7,656,638	B2	2/2010	Laakso et al.	
8,057,408	B2	11/2011	Cain et al.	
2001/0039420	A1	11/2001	Burbank et al.	
2001/0041163	A1	11/2001	Sugita et al.	
2002/0045890	A1	4/2002	Celliers et al.	
2002/0078964	A1	6/2002	Kovac et al.	
2002/0099356	A1	7/2002	Unger et al.	
2003/0092982	A1	5/2003	Eppstein	
2003/0112922	A1	6/2003	Burdette et al.	
2003/0149352	A1	8/2003	Liang et al.	
2003/0157025	A1	8/2003	Unger et al.	
2003/0181833	A1	9/2003	Faragalla et al.	
2003/0199857	A1	10/2003	Eizenhofer	
2003/0221561	A1	12/2003	Milo	
2004/0127815	A1	7/2004	Marchitto et al.	
2004/0138563	A1	7/2004	Moehring et al.	
2004/0236248	A1	11/2004	Svedman	
2004/0243021	A1	12/2004	Murphy et al.	
2005/0038339	A1	2/2005	Chauhan et al.	
2005/0038361	A1	2/2005	Zhong et al.	
2005/0152561	A1	7/2005	Spencer	
2005/0154314	A1	7/2005	Quistgaard	
2005/0283098	A1	12/2005	Conston et al.	
2006/0060991	A1	3/2006	Holsteyns et al.	
2006/0074303	A1	4/2006	Chornenky et al.	
2006/0206028	A1	9/2006	Lee et al.	
2006/0241466	A1	10/2006	Ottoboni et al.	
2006/0241523	A1	10/2006	Sinelnikov et al.	
2006/0264760	A1	11/2006	Liu et al.	
2006/0293630	A1	12/2006	Manna et al.	
2007/0010805	A1	1/2007	Fedewa et al.	
2007/0016039	A1	1/2007	Vortman et al.	
2007/0065420	A1	3/2007	Johnson	
2007/0083120	A1	4/2007	Cain et al.	
2007/0161902	A1	7/2007	Dan	
2007/0167764	A1	7/2007	Hynynen	
2007/0205785	A1	9/2007	Nilsson	
2007/0219448	A1	9/2007	Seip et al.	
2008/0013593	A1	1/2008	Kawabata	
2008/0055003	A1	3/2008	Unnikrishnan et al.	
2008/0082026	A1	4/2008	Schmidt et al.	
2008/0126665	A1	5/2008	Burr et al.	
2008/0214964	A1	9/2008	Chapelon et al.	
2008/0262345	A1	10/2008	Fichtinger et al.	
2008/0262486	A1	10/2008	Zvuloni et al.	
2008/0312561	A1	12/2008	Chauhan	
2009/0030339	A1	1/2009	Cheng et al.	
2009/0112098	A1	4/2009	Vaezy et al.	
2009/0177085	A1	7/2009	Maxwell et al.	
2009/0198094	A1	8/2009	Fenster et al.	
2009/0211587	A1	8/2009	Lawrentschuk	
2009/0227874	A1	9/2009	Suri et al.	
2010/0011845	A1	1/2010	Laugharn et al.	
2010/0069797	A1	3/2010	Cain et al.	
2010/0125225	A1	5/2010	Gelbart et al.	
2010/0163694	A1	7/2010	Fadler et al.	
2010/0261994	A1	10/2010	Davalos et al.	
2010/0286519	A1	11/2010	Lee et al.	
2010/0317971	A1	12/2010	Fan et al.	
2011/0040190	A1	2/2011	Jahnke et al.	
2011/0054315	A1	3/2011	Hall et al.	
2011/0054363	A1	3/2011	Cain et al.	
2011/0067624	A1	3/2011	Cain et al.	
2011/0112400	A1	5/2011	Emery et al.	
2011/0118602	A1	5/2011	Weng et al.	
2011/0172529	A1	7/2011	Gertner	
2011/0178444	A1	7/2011	Slayton et al.	
2011/0251528	A1	10/2011	Canney et al.	
2012/0010541	A1	1/2012	Cain et al.	
2012/0029353	A1	2/2012	Slayton et al.	
2012/0092724	A1	4/2012	Pettis	
2012/0130288	A1	5/2012	Holland et al.	
2012/0189998	A1	7/2012	Kruecker et al.	
2012/0259250	A1	10/2012	Sapozhnikov et al.	
2012/0271167	A1	10/2012	Holland et al.	
2013/0053691	A1	2/2013	Kawabata et al.	

FOREIGN PATENT DOCUMENTS

DE	3817094	A1	11/1989
EP	0017382	A1	10/1980
EP	0320303	A2	6/1989
EP	0332871	A2	9/1989
EP	0384831	A2	8/1990
EP	0755653	A1	1/1997
EP	1504713	A1	2/2005
GB	2099582	A	12/1982
JP	60-80779	A	5/1985
JP	61-196718	A	8/1986
JP	HEI 2-215451		8/1990
JP	HEI 6-197907	A	7/1994
JP	HEI 7-504339	A	5/1995
JP	08-84740	A	4/1996
JP	06-304178	A	5/1996
JP	08-131454	A	5/1996
JP	HEI 10-512477		12/1998
JP	2003-510159	A	3/2003
JP	2004-505660	A	2/2004
JP	2007520307	A	7/2007
JP	2010029650	A	2/2010
JP	2004-512502	A	4/2014
WO	WO94/06355	A1	3/1994
WO	WO 02/32506	A1	4/2002
WO	WO 2008/051484	A2	5/2008
WO	WO 2011/092683	A1	8/2011

OTHER PUBLICATIONS

Therapeutic Ultrasound Group. Non-invasive Ultrasonic Tissue Fraction for Treatment of Benign Disease and Cancer—"Histotripsy". University research [online]. Biomedical Engineering Department, University of Michigan. Jul. 2011[retrieved on Jan. 28, 2014] from: (http://web.archive.org/web/20110720091822/http://www.histotripsy.umich.edu/index.html>.entiredocument).

Aschoff et al.; How does alteration of hepatic blood flow affect liver perfusion and radiofrequency-induced thermal lesion size in rabbit liver?; J Magn Reson Imaging; 13(1); pp. 57-63; Jan. 2001.

Clasen et al.; MR-guided radiofrequency ablation of hepatocellular carcinoma: Long-term effectiveness; J Vasc Intery Radiol; 22(6); pp. 762-770; Jun. 2011.

Cline et al.; Magnetic resonance-guided thermal surgery; Magnetic Resonance in Medicine; 30(1); pp. 98-106; Jul. 1993.

Curiel et al.; Elastography for the follow-up of high-intensity focused ultrasound prostate cancer treatment: Initial comparison with MRI; Ultrasound Med. Biol; 31(11); pp. 1461-1468; Nov. 2005.

Emelianov et al.; Triplex ultrasound: Elasticity imaging to age deep venous thrombosis; Ultrasound Med Biol; 28(6); pp. 757-767; Jun. 2002.

(56) **References Cited**

OTHER PUBLICATIONS

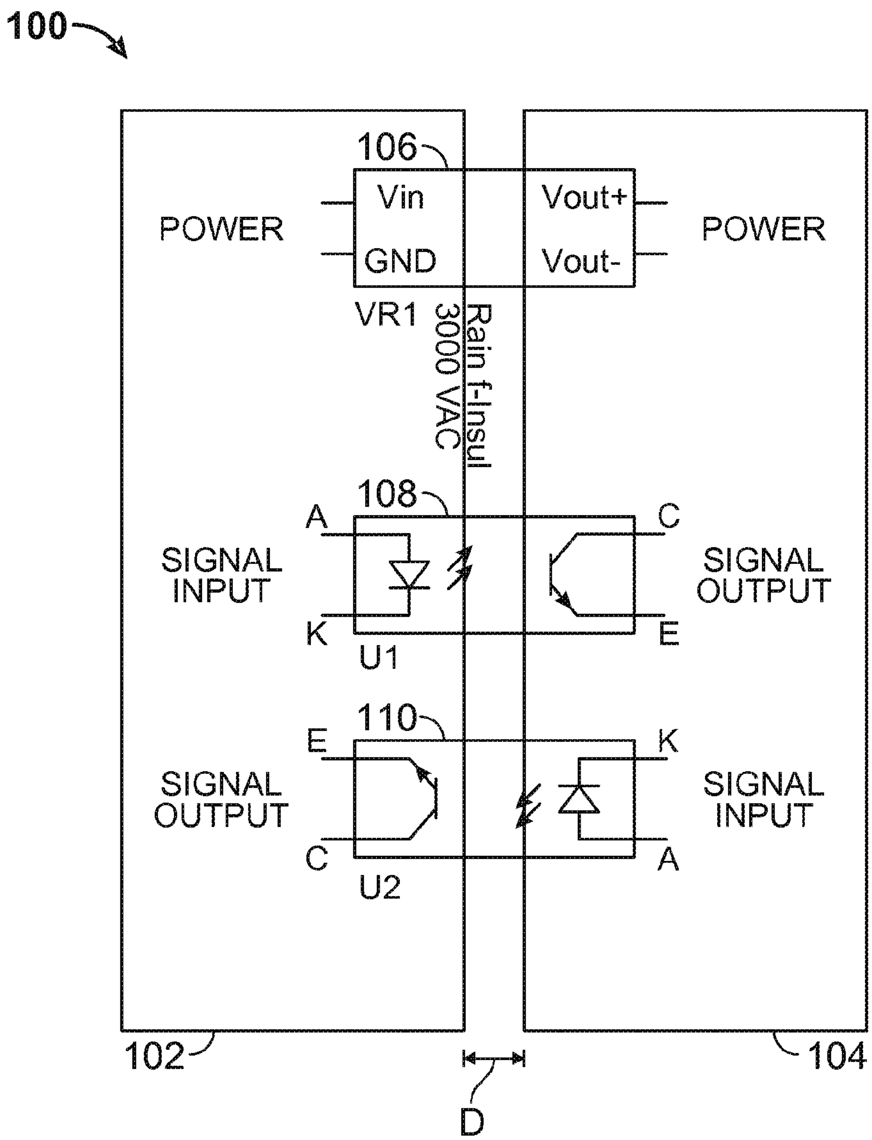
Hynynen et al.; Tissue thermometry during ultrasound exposure; European Urology; 23(Suppl 1); pp. 12-16; 1993 (year of pub. sufficiently earlier than effective US filing date and any foreign priority date).
Kallel et al.; The feasibility of elastographic visualization of HIFU-induced thermal lesions in soft tissues: Image-guided high-intensity focused ultrasound; Ultrasound Med. Biol; 25(4); pp. 641-647; May 1999.
Konofagou; Quo vadis elasticity imaging?; Ultrasonics; 42(1-9); pp. 331-336; Apr. 2004.
Kruse et al.; Tissue characterization using magnetic resonance elastography: Preliminary results; Phys. Med. Biol; 45(6); pp. 1579-1590; Jun. 2000.
Liu et al.; Real-time 2-D temperature imaging using ultrasound; IEEE Trans Biomed Eng; 57(1); pp. 12-16; Jan. 2010 (author manuscript, 16 pgs.).
Liu et al.; Viscoelastic property measurement in thin tissue constructs using ultrasound; IEEE Trans Ultrason Ferroelectr Freq Control; 55(2); pp. 368-383; Feb. 2008 (author manuscript, 37 pgs.).
Nightingale et al.; Analysis of contrast in images generated with transient acoustic radiation force; Ultrasound Med Biol; 32(1); pp. 61-72; Jan. 2006.
Okada et al.; A case of hepatocellular carcinoma treated by MR-guided focused ultrasound ablation with respiratory gating; Magn Reson Med Sci; 5(3); pp. 167-171; Oct. 2006.
Palmeri et al.; Acoustic radiation force-based elasticity imaging methods; Interface Focus; 1; pp. 553-564; Aug. 2011.
Rowland et al.; MRI study of hepatic tumours following high intensity focused ultrasound surgery; British Journal of Radiology; 70; pp. 144-153; Feb. 1997.
Sapareto et al.; Thermal dose determination in cancer therapy; Int J Radiat Oncol Biol Phys; 10(6); pp. 787-800; Apr. 1984.
Souchon et al.; Visualisation of HIFU lesions using elastography of the human prostate in vivo: Preliminary results; Ultrasound Med. Biol; 29(7); pp. 1007-1015; Jul. 2003.
Xie et al.; Correspondence of ultrasound elasticity imaging to direct mechanical measurement in aging DVT in rats; Ultrasound Med Biol; 31(10); pp. 1351-1359; Oct. 2005 (author manuscript, 20 pgs.).
Zhang et al.; A fast tissue stiffness-dependent elastography for HIFU-induced lesions inspection; Ultrasonics; 51(8); pp. 857-869; Dec. 2011.
Zheng et al.; An acoustic backscatter-based method for localization of lesions induced by high-intensity focused ultrasound; Ultrasound Med Biol; 36(4); pp. 610-622; Apr. 2010.
Xu et al.; U.S. Appl. No. 14/046,024 entitled "Bubble-induced color doppler feedback during histotripsy," filed Oct. 4, 2013.
Hall et al.; Histotripsy of the prostate: dose effects in a chronic canine model; Urology; 74(4); pp. 932-937; Oct. 2009 (author manuscript).
Lake et al.; Histotripsy: minimally invasive technology for prostatic tissue ablation in an in vivo canine model; Urology; 72(3); pp. 682-686; Sep. 2008.
Bertolina et al.; U.S. Appl. No. 13/735,936 entitled "Histotripsy Therapy Transducer," filed Jan. 7, 2013.
Cain, Charles A.; Histotripsy: controlled mechanical sub-division of soft tissues by high intensity pulsed ultrasound (conference presentation); American Institute of Physics (AIP) Therapeutic Ultrasound: 5th International Symposium on Therapeutic Ultrasound; 44 pgs.; Oct. 27-29, 2005.
Hall et al.; Imaging feedback of tissue liquefaction (histotripsy) in ultrasound surgery; IEEE Ultrasonic Symposium, 18-21 Sep. 2005, pp. 1732-1734.
Parsons et al.; Pulsed cavitational ultrasound therapy for controlled tissue homogenization; Ultrasound in Med. & Biol.; vol. 32(1); pp. 115-129; Jan. 2006.
Roberts et al.; Pulsed cavitational ultrasound: a noninvasive technology for controlled tissue ablation (histotripsy) in the rabbit kidney; Journal of Urology; vol. 175(2); pp. 734-738; Feb. 2006.
Xu et al.; A new strategy to enhance cavitational tissue erosion by using a high intensity initiating sequence; IEEE Trans Ultrasonics Ferroelectrics and Freq Control; vol. 53(8); pp. 1412-1424; Aug. 2006.
Xu et al.; Controlled ultrasound tissue erosion: the role of dynamic interaction between insonation and microbubble activity; Journal of the Acoustical Society of America; vol. 117(1); pp. 424-435; Jan. 2005.
Xu et al.; Controlled ultrasound tissue erosion; IEEE Transaction on Ultrasonics, Ferroelectrics, and Frequency Control; vol. 51 (6); pp. 726-736; Jun. 2004.
Xu et al.; Effects of acoustic parameters on bubble cloud dynamics in ultrasound tissue erosion (histotripsy); Journal of the Acoustical Society of America; vol. 122(1); pp. 229-236; Jul. 2007.
Xu et al.; High Speed Imaging of Bubble Clouds Generated in Pulsed Ultrasound Cavitational Therapy'Histotripsy; IEEE Trans Ultrason Ferroelectr Freq Control; ; vol. 54; No. 10; pp. 2091R2101; Oct. 2007.
Xu et al.; Investigation of intensity threshold for ultrasound tissue erosion; Ultrasound in Med. & Biol.; vol. 31(12); pp. 1673-1682; Dec. 2005.
Xu et al.; Optical and acoustic monitoring of bubble cloud dynamics at a tissue-fluid interface in ultrasound tissue erosion; Journal of the Acoustical Society of America; vol. 121(4); pp. 2421-2430; Apr. 2007.
Cain et al.; U.S. Appl. No. 13/648,955 entitled "Pulsed Cavitational Therapeutic Ultrasound With Dithering," filed Oct. 10, 2012.
Cain et al.; U.S. Appl. No. 13/648,965 entitled "Imaging Feedback of Histotripsy Treatments with Ultrasound Transient Elastography," filed Oct. 10, 2012.
Appel et al.; Stereoscopic highspeed recording of bubble filaments; Ultrasonics Sonochemistry; vol. 11(1); pp. 39-42; Jan. 2004.
Atchley et al.; Thresholds for cavitation produced in water by pulsed ultrasound; Ultrasonics.; vol. 26(5); pp. 280-285; Sep. 1988.
Bland et al.; Surgical Oncology; McGraw Hill; Chap. 5 (Cavitron Ultrasonic Aspirator); pp. 461-462; Jan. 29, 2001.
Burdin et al.; Implementation of the laser diffraction technique for cavitation bubble investigations; Particle & Particle Systems Characterization; vol. 19; pp. 73-83; May 2002.
Holland et al.; Thresholds for transient cavitation produced by pulsed ultrasound in a controlled nuclei environment; J. Acoust. Soc. Am.; vol. 88(5); pp. 2059-2069; Nov. 1990.
Huber et al.; Influence of shock wave pressure amplitude and pulse repetition frequency on the lifespan, size and number of transient cavities in the field of an electromagnetic lithotripter; Physics in Medicine and Biology; vol. 43 (10); pp. 3113-3128; Oct 1998.
Lauterborn et al.; Cavitation bubble dynamics studied by high speed photography and holography: part one; Ultrasonics; vol. 23; pp. 260-268; Nov. 1985.
Miller et al.; A review of in vitro bioeffects of inertial ultrasonic cavitation from a mechanistic perspective; Ultrasound in Medicine and Biology; vol. 22; pp. 1131-1154; (year of publication is sufficiently earlier than the effective U.S. filed and any foreign priority date) 1996.
Ohl et al.; Bubble dynamics, shock waves and sonoluminescence; Phil. Trans. R. Soc. Lond. A; vol. 357; pp. 269-294; (year of publication is sufficiently earlier than the effective U.S. filed and any foreign priority date) 1999.
Pishchalnikov et al.; Cavitation Bubble Cluster Activity in the Breakage of Kidney Stones by Lithotripter Shock Waves; J Endourol.; 17(7): 435-446; Sep. 2003.
Porter et al.; Reduction in left ventricular cavitary attenuation and improvement in posterior myocardial contrast . . . ; J Am Soc Echocardiography; pp. 437-441; Jul.-Aug. 1996.
Roy et al.; A precise technique for the measurement of acoustic cavitation thresholds and some preliminary results; Journal of the Acoustical Society of America; vol. 78(5); pp. 1799-805; Nov. 1985.
Sapozhnikov et al.; Ultrasound-Guided Localized Detection of Cavitation During Lithotripsy in Pig Kidney in Vivo; IEEE Ultrasonics Symposium, vol. 2; pp. 1347-1350; Oct. 7-10, 2001.
Sokolov et al.; Use of a dual-pulse lithotripter to generate a localized and intensified cavitation field; Journal of the Acoustical Society of America; vol. 110(3); pp. 1685-1695; Sep. 2001.

(56) **References Cited**

OTHER PUBLICATIONS

Cain, Charles A.; U.S. Appl. No. 13/570,708 entitled "Lesion Generation Through Bone Using Histotripsy Therapy Without Aberration Correction," filed Aug. 9, 2012.
Avago Technologies; ACNV2601 High Insulation Voltage 10 MBd Digital Opotcoupler. Avago Technologies Data Sheet; pp. 1-11; Jul. 29, 2010.
Canney et al.; Shock-Induced Heating and Millisecond Boiling in Gels and Tissue Due to High Intensity Focused Ultrasound; Ultrasound in Medicine & Biology, vol. 36, pp. 250-267; Feb. 2010 (author manuscript).
Chan et al.; An image-guided high intensity focused ultrasound device for uterine fibroids treatment; Medical Physics, vol. 29, pp. 2611-2620, Nov. 2002.
Clement et al.; A hemisphere array for non-invasive ultrasound brain therapy and surgery; Physics in Medicine and Biology, vol. 45, p. 3707-3719, Dec. 2000.
Desilets et al.; The Design of Efficient Broad-Band Piezoelectric Transducers; Sonics and Ultrasonics, IEEE Transactions on, vol. 25, pp. 115-125, May 1978.
Giannatsis et al.; Additive fabrication technologies applied to medicine and health care: a review; The International Journal of Advanced Manufacturing Technology; 40(1-2); pp. 116-127; Jan. 2009.
Gudra et al.; Influence of acoustic impedance of multilayer acoustic systems on the transfer function of ultrasonic airborne transducers; Ultrasonics, vol. 40, pp. 457-463, May 2002.
Hall et al.; A Low Cost Compact 512 Channel Therapeutic Ultrasound System for Transcutaneous Ultrasound Surgery; AIP Conference Proceedings, Boston, MA; vol. 829, pp. 445-449, Oct. 27-29, 2005.
Hall et al.; Acoustic Access to the Prostate for Extracorporeal Ultrasound Ablation; Journal of Endourology, vol. 24, pp. 1875-1881, Nov. 2010.
Hartmann; Ultrasonic properties of poly(4-methyl pentene-1), Journal of Applied Physics, vol. 51, pp. 310-314, Jan. 1980.
Kim et al.; Dependence of particle volume fraction on sound velocity and attenuation of EPDM composites; Ultrasonics, vol. 46, pp. 177-183, Feb. 2007.
Krimholtz et al.; New equivalent circuits for elementary piezoelectric transducers; Electronics Letters, vol. 6, pp. 398-399, Jun. 1970.
Lensing et al.; Deep-vein thrombosis; The Lancet, vol. 353, pp. 479-485, Feb. 6, 1999.
Manes et al.; Design of a Simplified Delay System for Ultrasound Phased Array Imaging; Sonics and Ultrasonics, IEEE Transactions on, vol. 30, pp. 350-354, Nov. 1983.
Maréchal et al; Effect of Radial Displacement of Lens on Response of Focused Ultrasonic Transducer; Japanese Journal of Applied Physics, vol. 46, p. 3077-3085; May 15, 2007.
Maréchal et al; Lens-focused transducer modeling using an extended KLM model; Ultrasonics, vol. 46, pp. 155-167, May 2007.
Martin et al.; Water-cooled, high-intensity ultrasound surgical applicators with frequency tracking; Ultrasonics, Ferroelectrics and Frequency Control, IEEE Transactions on, vol. 50, pp. 1305-1317, Oct. 2003.
Maxwell et al.; Noninvasive Thrombolysis Using Pulsed Ultrasound Cavitation Therapy—Histotripsy; Ultrasound in Medicine & Biology, vol. 35, pp. 1982-1994, Dec. 2009 (author manuscript).
Parsons et al.; Cost-effective assembly of a basic fiber-optic hydrophone for measurement of high-amplitude therapeutic ultrasound fields; The Journal of the Acoustical Society of America, vol. 119, pp. 1432-1440, Mar. 2006.
Rosenschein et al.; Ultrasound Imaging-Guided Noninvasive Ultrasound Thrombolysis: Preclinical Results; Circulation; vol. 102; pp. 238-245, Jul. 11, 2000.
Sato et al.; Experimental Investigation of Phased Array Using Tapered Matching Layers. 2002 IEEE Ultrasound Symposium. vol. 2; pp. 1235-1238, Oct. 2002.
Simonin et al.; Characterization of heterogeneous structure in a polymer object manufactured by stereolithography with low-frequency microechography; Journal of Materials Chemistry; vol. 6, pp. 1595-1599, Sep. 1996.
Song et al.; Feasibility of Using Lateral Mode Coupling Method for a Large Scale Ultrasound Phased Array for Noninvasive Transcranial Therapy; Biomedical Engineering; IEEE Transactions on, vol. 57, pp. 124-133; Jan. 2010 (author manuscript).
Souquet et al.; Design of Low-Loss Wide-Band Ultrasonic Transducers for Noninvasive Medical Application; Sonics and Ultrasonics, IEEE Transactions on, vol. 26, pp. 75-80, Mar. 1979.
Toda; Narrowband impedance matching layer for high efficiency thickness mode ultrasonic transducers; Ultrasonics, Ferroelectrics and Frequency Control, IEEE Transactions on, vol. 49, pp. 299-306, Mar. 2002.
Van Kervel et al.; A calculation scheme for the optimum design of ultrasonic transducers; Ultrasonics, vol. 21, pp. 134-140, May 1983.
Wang et al.; Quantitative ultrasound backscatter for pulsed cavitational ultrasound therapy-histotripsy; Ultrasonics, Ferroelectrics and Frequency Control, IEEE Transactions on, vol. 56, pp. 995-1005, May 2009 (author manuscript).
Yan et al.; A review of rapid prototyping technologies and systems; Computer-Aided Design, vol. 28, pp. 307-318, Apr. 1996.
Akiyama et al.; Elliptically curved acoustic lens for emitting strongly focused finite-amplitude beams: Application of the spheroidal beam equation model to the theoretical prediction; Acoustical Science and Technology, vol. 26, pp. 279-284, May 2005.
Hall et al.; U.S. Appl. No. 13/874,083 entitled "Ultrasound Transducer Manufacturing Using Rapid-Prototyping Method," filed Apr. 30, 2013.
Cain et al.; U.S. Appl. No. 13/943,621 entitled "Devices and Methods for Using Controlled Bubble Cloud Cavitation in Fractionating Urinary Stones," filed Jul. 16, 2013.
Teofilovic et al.; U.S. Appl. No. 14/024,394 entitled "Histotripsy Therapy System," filed Sep. 11, 2013.
Avtech; AVR-8 Data sheet; May 23, 2004; 3 pages; retrieved from the internet (http//www.avtechpulse.com).
Cannata et al.; U.S. Appl. No. 14/323,693 entitled "Histotripsy excitation sequences optimized for bubble cloud formation using shock scattering," filed Jul. 3, 2014.

* cited by examiner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106
Vin
GND
Vout+
Vout-
POWER
POWER
VR1
Rain f-Insul
3000 VAC
108
A
K
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E
SIGNAL
INPUT
SIGNAL
OUTPUT
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SIGNAL
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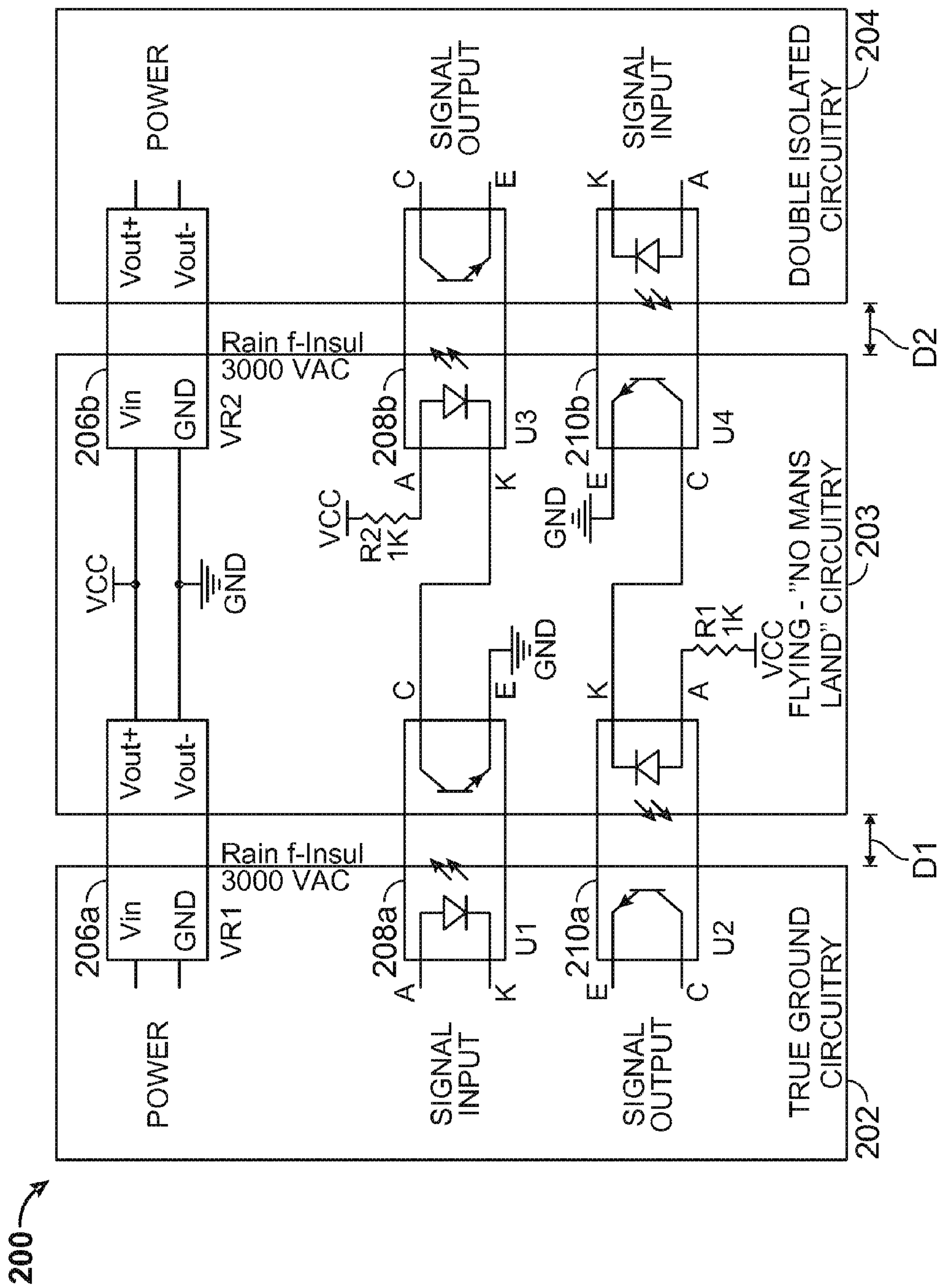
SIGNAL
INPUT
U2
102
104
D

FIG. 1

FIG. 2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TRUE GROUND CIRCUITRY
202
POWER
SIGNAL INPUT
SIGNAL OUTPUT
206a
Vin
GND
VR1
Vout+
Vout-
Rain f-Insul
3000 VAC
208a
U1
210a
U2
D1
FLYING - "NO MANS LAND" CIRCUITRY
203
VCC
GND
R1
1K
R2
1K
206b
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204
A
K
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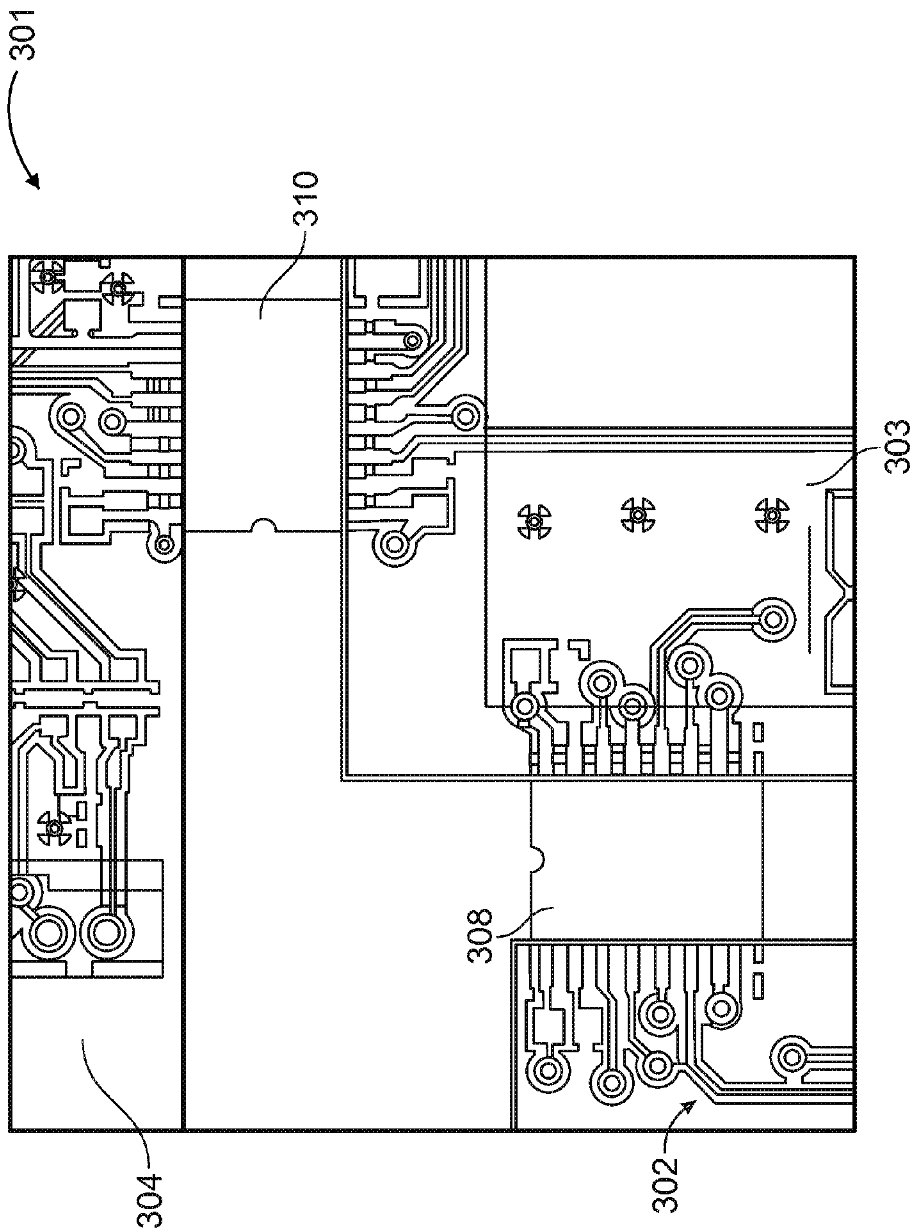


FIG. 3

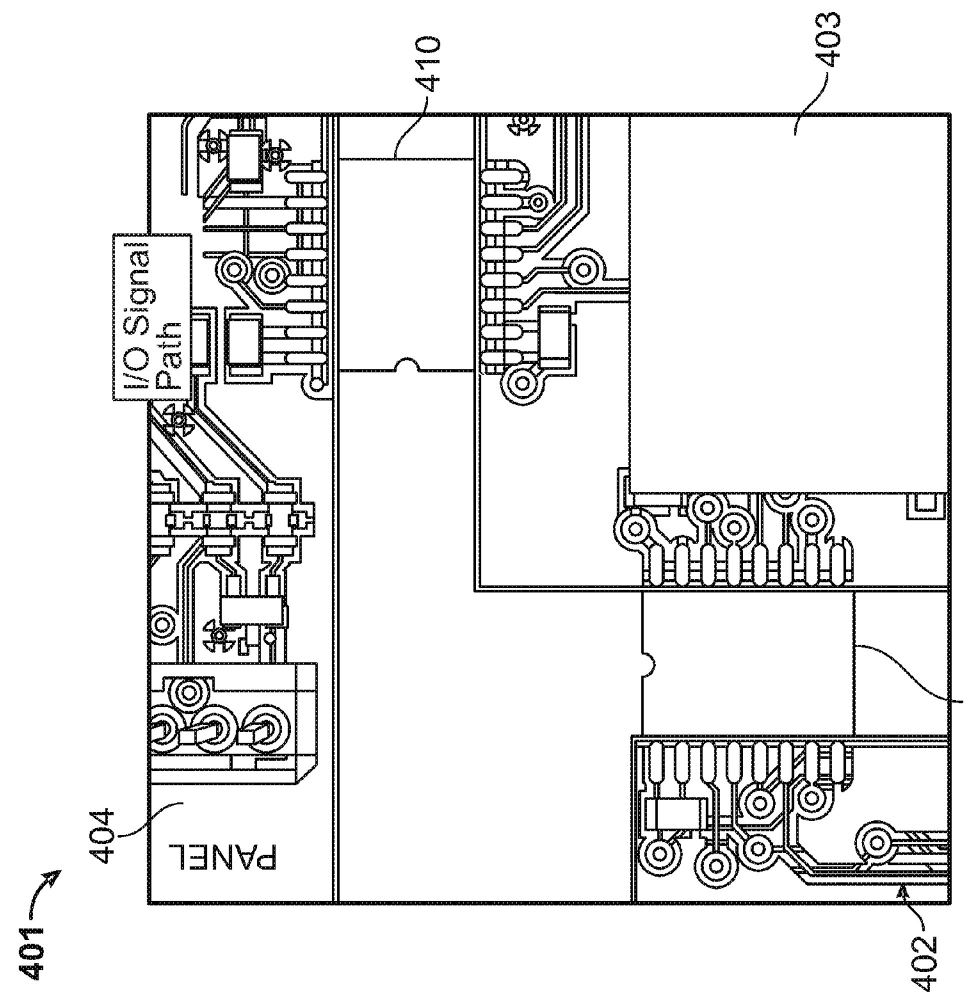
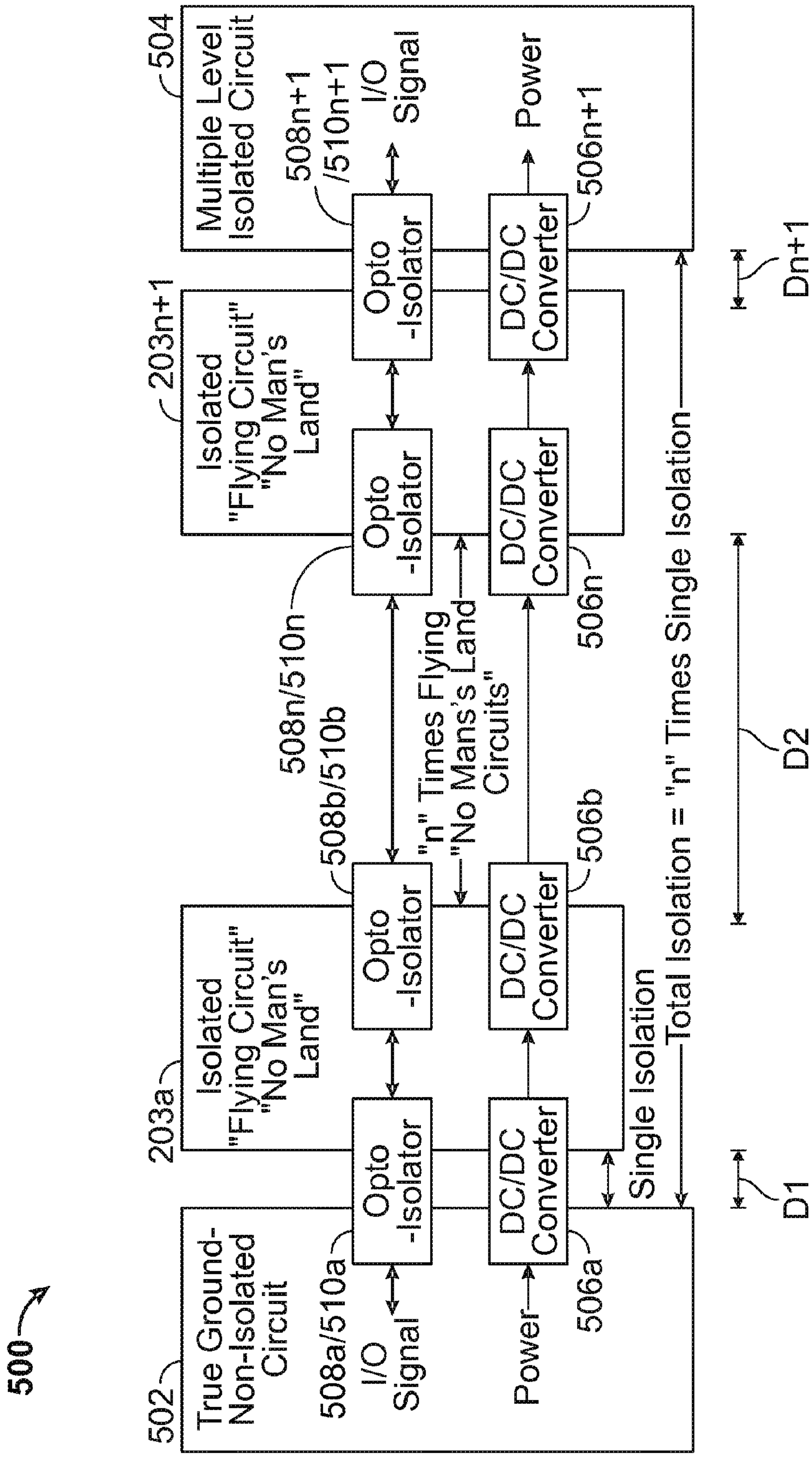


FIG. 4



500
502
True Ground-Non-Isolated Circuit
508a/510a
I/O Signal
Power
506a
Opto -Isolator
DC/DC Converter
D1
Single Isolation
203a
Isolated "Flying Circuit" "No Man's Land"
Opto -Isolator
DC/DC Converter
508b/510b
506b
"n" Times Flying "No Mans's Land Circuits"
508n/510n
D2
Total Isolation = "n" Times Single Isolation
203n+1
Isolated "Flying Circuit" "No Man's Land"
Opto -Isolator
DC/DC Converter
506n
Opto -Isolator
DC/DC Converter
Dn+1
504
Multiple Level Isolated Circuit
508n+1 /510n+1
I/O Signal
Power
506n+1

FIG. 5

SYSTEMS AND METHODS FOR OBTAINING LARGE CREEPAGE ISOLATION ON PRINTED CIRCUIT BOARDS

INCORPORATION BY REFERENCE

All publications and patent applications mentioned in this specification are herein incorporated by reference to the same extent as if each individual publication or patent application was specifically and individually indicated to be incorporated by reference.

FIELD

The present disclosure relates generally to powering medical devices. More specifically, the present disclosure relates to obtaining sufficient creepage insulation distances required for high voltage medical devices.

BACKGROUND

Medical devices having electrical components typically must meet various electrical safety standards imposed by governing bodies (for example, in the United States, medical electrical equipment must satisfy the general standard IEC 60601-1 published by the International Electrotechnical Commission). One of the major concerns in electrical devices is electrical isolation. In applications where high voltages are used in close proximity to a patient, it can be very challenging to achieve the proper level of electrical isolation, since as the voltage used increases, the creepage distance and air clearance required must also be increased.

Generally, opto-isolators are used to transfer a signal over an isolation barrier, and DC to DC converters or transformers are used to transfer power over the isolation barriers. Opto-isolators currently on the market are capable of obtaining creepage insulation up to approximately 7 mm. However, in very high voltage devices, these opto-isolators are not capable of achieving the creepage insulation required by IEC 60601-1.

FIG. **1** illustrates an electrical circuit system **100** including a true ground circuit **102** and a single isolated circuit **104**. In FIG. **1**, the two circuits **102** and **104** are separated by a creepage insulation distance D. Power can be transmitted between the two circuits with, for example, an isolated DC to DC converter, and the input/output signals can be transmitted between the circuits with opto-isolators **108** and **110**. As known in the art, opto-isolators are electronic devices configured to transfer electrical signals via light waves (e.g., from a light-emitting diode (LED) to a photosensor (such as a phototransistor or photoresistor). In the illustrative schematic shown in FIG. **1**, traditional opto-isolators are typically capable of providing creepage isolation distances D up to ~7 mm.

Thus, methods and systems are required for high voltage medical devices to obtain creepage isolation of at least 12 mm-14 mm.

SUMMARY OF THE DISCLOSURE

In one embodiment, an electrical circuit is provided, comprising a ground circuit, a floating circuit optically coupled to the ground circuit, the floating circuit being electrically isolated from the ground circuit by a first creepage isolation distance, and an isolated circuit optically coupled to the floating circuit, the isolated circuit being electrically isolated from the floating circuit by a second creepage isolation distance,

the isolated circuit being electrically isolated from the ground circuit by a total creepage isolation distance equal to a combination of the first and second creepage isolation distances.

In some embodiments, the total creepage isolation distance is at least twice as large as the first creepage isolation distance.

In other embodiments, the circuit further comprises a first opto-isolator configured to optically couple a signal input from the ground circuit to the floating circuit. In another embodiment, the circuit further comprises a second opto-isolator configured to optically couple the signal input from the floating circuit to the isolated circuit.

In one embodiment, the first opto-isolator comprises a diode disposed on the ground circuit and a transistor disposed on the floating circuit. In another embodiment, the second opto-isolator comprises a diode disposed on the floating circuit and a transistor disposed on the isolated circuit.

In some embodiments, the circuit further comprises a first opto-isolator configured to optically couple a signal input from the isolated circuit to the floating circuit. In one embodiment, the circuit further comprises a second opto-isolator configured to optically couple the signal input from the floating circuit to the ground circuit.

In one embodiment, the first opto-isolator comprises a diode disposed on the isolated circuit and a transistor disposed on the floating circuit. In another embodiment, the second opto-isolator comprises a diode disposed on the floating circuit and a transistor disposed on the ground circuit.

In some embodiments, the first creepage isolation distance is approximately 7 mm. In another embodiment, the second creepage isolation distance is approximately 7 mm and the total creepage isolation distance is approximately 14 mm.

In one embodiment, the ground circuit, floating circuit, and double isolated circuit are disposed on a printed circuit board.

An electrical circuit is provided, comprising, a ground circuit, a first floating circuit optically coupled to the ground circuit, the first floating circuit being electrically isolated from the ground circuit by a first creepage isolation distance, a second floating circuit optically coupled to the first floating circuit, the second floating circuit being electrically isolated from the first floating circuit by a second creepage isolation distance, and a triple isolated circuit optically coupled to the second floating circuit, the triple isolated circuit being electrically isolated from the second floating ground circuit by third creepage isolation distance, the triple isolated circuit being isolated from the ground circuit by a total creepage isolation distance equal to a combination of the first, second, and third creepage isolation distance,

In some embodiments, the total creepage isolation distance is at least three times as large as the first creepage isolation distance.

In one embodiment, the circuit further comprises a first opto-isolator configured to optically couple a signal input from the ground circuit to the first floating circuit. In another embodiment, the circuit further comprises a second opto-isolator configured to optically couple the signal input from the first floating circuit to the second floating circuit. In an additional embodiment, the circuit further comprises a third opto-isolator configured to optically couple the signal input from the second floating circuit to the triple isolated circuit.

In some embodiments, the first opto-isolator comprises a diode disposed on the ground circuit and a transistor disposed on the first floating circuit. In another embodiment, the second opto-isolator comprises a diode disposed on the first floating circuit and a transistor disposed on the second floating circuit. In an additional embodiment, the third opto-isolator comprises a diode disposed on the second floating circuit and a transistor disposed on the triple isolated circuit.

A method of increasing a creepage isolation distance in an electrical circuit is also provided, comprising optically coupling a ground circuit to a floating circuit to electrically isolate the floating circuit from the ground circuit by a first creepage isolation distance, and optically coupling an isolated circuit to the floating circuit to electrically isolate the isolated circuit from the floating circuit by a second creepage isolation distance, and to electrically isolate the isolated circuit from the ground circuit by a total creepage isolation distance equal to a combination of the first and second creepage isolation distances.

In some embodiments of the method, optically coupling comprises optically coupling with an opto-isolator. In another embodiment, the total creepage isolation distance is approximately 14 mm.

BRIEF DESCRIPTION OF THE DRAWINGS

The novel features of the invention are set forth with particularity in the claims that follow. A better understanding of the features and advantages of the present invention will be obtained by reference to the following detailed description that sets forth illustrative embodiments, in which the principles of the invention are utilized, and the accompanying drawings of which:

FIG. **1** illustrates an electrical circuit having a ground circuit and a single isolated circuit.

FIG. **2** illustrates an electrical circuit having a ground circuit, a floating circuit, and a double isolated circuit.

FIG. **3** is a schematic drawing of one embodiment of a printed circuit board layout including the circuits described above in FIG. **2**.

FIG. **4** illustrates a 3D view of the printed circuit board of FIG. **3**.

FIG. **5** illustrates one embodiment which can provide an isolation creepage distance of n times a single isolation distance (e.g. n times 7 mm of creepage distance for conventional opto-isolators).

DETAILED DESCRIPTION

The present disclosure describes and illustrates effective and inexpensive methods and systems for obtaining a wide range of creepage isolation distances. These methods and systems are particularly well suited for high-voltage medical device applications where large creepage isolation distances are required by law or statute.

FIG. **2** illustrates a schematic electrical diagram of one embodiment of an electrical circuit **200** configured to provide large (e.g., up to 14 mm) creepage isolation distances. The electrical circuit can be disposed on, for example, a printed circuit board. As shown in FIG. **2**, circuit **200** can include ground circuit **202**, floating circuit **203**, and double isolated circuit **204**. Power can be transmitted from the ground circuit **202** to the double isolated circuit **204** via a pair of isolated DC to DC converters **206***a* and **206***b*. The input/output signals can be transmitted from the ground circuit **202** to the double isolated circuit **204** via opto-isolators **208***a* and **208***b* (signal input) and opto-isolators **210***a* and **210***b* (signal output).

Ground circuit **202** can be in optical/electrical communication with floating circuit **203**, and floating circuit **203** can be in optical/electrical communication with double isolated circuit **204**. The opto-isolators used for coupling the circuits can be electronic devices configured to transfer electrical signals via light waves (e.g., from a light-emitting diode (LED) to a photosensor (such as a phototransistor or photoresistor).

Opto-isolators typically have an LED as an input and various components at the output (e.g., mosfet, IGBT, logic gate, triac, Darlington, etc).

As shown in FIG. **2**, opto-isolator **208***a* can comprise a diode in ground circuit **202** optically coupled to a transistor in floating circuit **203** for communicating signal inputs from the ground circuit to the floating circuit. Similarly, opto-isolator **210***a* can comprise a diode in floating circuit **203** optically coupled to a transistor in ground circuit **202** for communicating signal outputs from the floating circuit to the ground circuit. A similar configuration can communicate signal inputs and outputs from the floating circuit to the double isolated circuit, namely, opto-isolator **208***b* comprising a diode in the floating circuit optically coupled to a transistor in the double isolated circuit, and opto-isolator **210***b* comprising a diode in the double isolated circuit optically coupled to a transistor in the floating circuit.

In one embodiment, the electrical circuit of FIG. **2** comprises a ground circuit **202**, a floating circuit **203** optically coupled to the ground circuit via opto-isolators **208***a* and **210***a*, the floating circuit being electrically isolated from the ground circuit by a first creepage isolation distance D**1**, and an isolated circuit optically coupled to the floating circuit via opto-isolators **208***b* and **210***b*, the isolated circuit being electrically isolated from the floating circuit by a second creepage isolation distance, the isolated circuit being electrically isolated from the ground circuit by a total creepage isolation distance equal to a combination of the first and second creepage isolation distances.

The electrical circuit **200** of FIG. **2** can be configured to optically couple a signal input from the ground circuit to the floating circuit, and to optically couple the signal input from the floating circuit to the isolated circuit. Similarly, the electrical circuit of FIG. **2** can be configured to optically couple a signal input from the isolated circuit to the floating circuit, and to optically couple the signal input from the floating circuit to the ground circuit.

The floating circuit is isolated from the ground and isolated circuits because there is no physical point of contact between the floating circuit and either the ground or isolated circuits. Instead, the floating circuit is optically coupled to both the ground and isolated circuits. The values of the resistors in the floating circuit are calculated using ohms law and depend on the LED forward current, LED voltage drop, and VCC voltage. In some embodiments, very fast opto-isolators with logic output can be used to keep delays less than 10 ns.

In FIG. **2**, the addition of floating circuit **203** between ground circuit **202** and double isolated circuit **204** allows system **200** to essentially double the creepage isolation distances obtainable with a single conventional opto-isolator. In FIG. **2**, the creepage isolation distance effectively becomes D1+D2, or 2×D. Since conventional opto-isolators are capable of approximately ~7 mm of creepage isolation, the system of FIG. **2** is capable of providing up to approximately ~14 mm of creepage isolation. It should be understood that if opto-isolators are capable of providing more than the ~7 mm of creepage isolation, the circuit systems described herein would still be capable of providing double the creepage isolation distances obtainable with a single opto-isolator.

FIG. **3** is a schematic drawing of one embodiment of a printed circuit board layout including the circuits described above in FIG. **2**. In FIG. **3**, printed circuit board **301** can include ground circuit **302**, floating circuit **303**, and double isolated circuit **304**. Ground circuit **302** can be electrically isolated from floating circuit **303** via opto-isolator **308**. Similarly, double isolated circuit **304** can be electrically isolated from floating circuit **303** via opto-isolator **310**. As shown in the diagram, this embodiment provides a creepage isolation distance of 7.24 mm+7.43 mm for a total of approximately 14.73 mm of isolation.

FIG. **4** illustrates a 3D view of the printed circuit board of FIG. **3**. Printed circuit board **401** includes all of the same features of the PCB layout of FIG. **3**, including ground circuit **402**, floating circuit **403**, and double isolated circuit **404**, and opto-isolators **408** and **410**. PCB **401** also illustrates the input/output signal path from ground circuit **402**, through floating circuit **403**, to double isolated circuit **404** and back. During a PCB layout process, it is important that the creepage requirements are met throughout the entire PCB. The circuits shown in FIGS. **3** and **4** satisfy the requirement of having a minimum of ~14 mm of creepage distance throughout the entire PCB.

The embodiments described above can be further applied to providing even larger isolation creepage distances by using multiple floating circuits. FIG. **5** illustrates one embodiment which can provide an isolation creepage distance of n times a single isolation distance (e.g. n times 7 mm of creepage distance for conventional opto-isolators). In FIG. **5**, multiple floating circuits are disposed between the ground circuit **502** and the isolated circuit **504**. The amount of creepage distance desired determines the number of floating circuits used. For example, to achieve approximately 21 mm of creepage distance with a conventional opto-insulator, a total of two floating circuits can be used between the ground and isolated circuits. The input/output signals can be optically transmitted from the ground circuit, through the floating circuits, to the isolated circuit, via opto-insulators **508***a*/**510***a* through **508***n*+1/**510***n*+1. Similarly, n+1 DC/DC converters can transfer power from the ground circuit, through the floating circuits, to the isolated circuit. This configuration provides for a total isolation creepage distance of n times the amount of isolation provided by a single opto-insulator. For example, assuming an opto-isolator capable of providing 7 mm of isolation, two floating circuits would provide ~21 mm of isolation, three floating circuits would provide ~28 mm of isolation, and so forth.

Referring to FIG. **5**, an electrical circuit with two floating circuits (and a total of ~21 mm of isolation with conventional opto-isolators) can be described. In this embodiment, the electrical circuit of FIG. **5** comprises a ground circuit **502**, a first floating circuit **203***a* optically coupled to the ground circuit via opto-isolators **508***a* and **510***a*, the floating circuit being electrically isolated from the ground circuit by a first creepage isolation distance D**1**, a second floating circuit **203***n*+1 optically coupled to the first floating circuit via opto-isolators **508***b* and **510***b*, the second floating circuit being electrically isolated from the ground circuit by a first creepage isolation distance D**1** and a second creepage isolation distance D**2**, the electrical circuit further comprising an isolated circuit optically coupled to the second floating circuit via opto-isolators **508***n*+1 and **510***n*+1, the isolated circuit being electrically isolated from the floating circuit by a third creepage isolation distance, the isolated circuit being electrically isolated from the ground circuit by a total creepage isolation distance equal to a combination of the first, second, and third creepage isolation distances.

In this example, the circuit can be configured to optically couple a signal input from the ground circuit to the first floating circuit, to optically couple the signal input from the first floating circuit to the second floating circuit, and to optically couple the signal input from the second floating circuit to the isolated circuit. Similarly, the electrical circuit of FIG. **5** can be configured to optically couple a signal input from the isolated circuit to the second floating circuit, to optically couple the signal input from the second floating circuit to the first floating circuit, and to optically couple the signal input from the first floating circuit to the ground circuit

As for additional details pertinent to the present invention, materials and manufacturing techniques may be employed as within the level of those with skill in the relevant art. The same may hold true with respect to method-based aspects of the invention in terms of additional acts commonly or logically employed. Also, it is contemplated that any optional feature of the inventive variations described may be set forth and claimed independently, or in combination with any one or more of the features described herein. Likewise, reference to a singular item, includes the possibility that there are plural of the same items present. More specifically, as used herein and in the appended claims, the singular forms "a," "and," "said," and "the" include plural referents unless the context clearly dictates otherwise. It is further noted that the claims may be drafted to exclude any optional element. As such, this statement is intended to serve as antecedent basis for use of such exclusive terminology as "solely," "only" and the like in connection with the recitation of claim elements, or use of a "negative" limitation. Unless defined otherwise herein, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. The breadth of the present invention is not to be limited by the subject specification, but rather only by the plain meaning of the claim terms employed.

What is claimed is:

1. An electrical circuit, comprising:

a ground circuit;

a floating circuit optically coupled to the ground circuit with a first opto-isolator, the floating circuit being electrically isolated from the ground circuit by a first creepage isolation distance; and

an isolated circuit optically coupled to the floating circuit with a second opto-isolator, the isolated circuit being electrically isolated from the floating circuit by a second creepage isolation distance, the first opto-isolator being electrically connected to the second opto-isolator in series so that the isolated circuit is electrically isolated from the ground circuit by a total creepage isolation distance equal to a combination of the first and second creepage isolation distances.

2. The electrical circuit of claim **1** wherein the total creepage isolation distance is at least twice as large as the first creepage isolation distance.

3. The electrical circuit of claim **1** wherein the first opto-isolator is configured to optically couple a signal input from the ground circuit to the floating circuit.

4. The electrical circuit of claim **3** wherein the second opto-isolator is configured to optically couple the signal input from the floating circuit to the isolated circuit.

5. The electrical circuit of claim **3** wherein the first opto-isolator comprises a diode disposed on the ground circuit and a transistor disposed on the floating circuit.

6. The electrical circuit of claim **4** wherein the second opto-isolator comprises a diode disposed on the floating circuit and a transistor disposed on the isolated circuit.

7. The electrical circuit of claim **1** wherein the first opto-isolator is configured to optically couple a signal input from the isolated circuit to the floating circuit.

8. The electrical circuit of claim **7** wherein the second opto-isolator is configured to optically couple the signal input from the floating circuit to the ground circuit.

9. The electrical circuit of claim **7** wherein the first opto-isolator comprises a diode disposed on the isolated circuit and a transistor disposed on the floating circuit.

10. The electrical circuit of claim 8 wherein the second opto-isolator comprises a diode disposed on the floating circuit and a transistor disposed on the ground circuit.

11. The electrical circuit of claim 1 wherein the first creepage isolation distance is approximately 7 mm.

12. The electrical circuit of claim 1 wherein the second creepage isolation distance is approximately 7 mm and the total creepage isolation distance is approximately 14 mm.

13. The electrical circuit of claim 1 wherein the ground circuit, floating circuit, and double isolated circuit are disposed on a printed circuit board.

14. An electrical circuit, comprising:
a ground circuit;
a first floating circuit optically coupled to the ground circuit, the first floating circuit being electrically isolated from the ground circuit by a first creepage isolation distance;
a second floating circuit optically coupled to the first floating circuit, the second floating circuit being electrically isolated from the first floating circuit by a second creepage isolation distance; and
a triple isolated circuit optically coupled to the second floating circuit, the triple isolated circuit being electrically isolated from the second floating ground circuit by a third creepage isolation distance, the triple isolated circuit being isolated from the ground circuit by a total creepage isolation distance equal to a combination of the first, second, and third creepage isolation distances.

15. The electrical circuit of claim 14 wherein the total creepage isolation distance is at least three times as large as the first creepage isolation distance.

16. The electrical circuit of claim 14 further comprising a first opto-isolator configured to optically couple a signal input from the ground circuit to the first floating circuit.

17. The electrical circuit of claim 16 further comprising a second opto-isolator configured to optically couple the signal input from the first floating circuit to the second floating circuit.

18. The electrical circuit of claim 17 further comprising a third opto-isolator configured to optically couple the signal input from the second floating circuit to the triple isolated circuit.

19. The electrical circuit of claim 16 wherein the first opto-isolator comprises a diode disposed on the ground circuit and a transistor disposed on the first floating circuit.

20. The electrical circuit of claim 17 wherein the second opto-isolator comprises a diode disposed on the first floating circuit and a transistor disposed on the second floating circuit.

21. The electrical circuit of claim 18 wherein the third opto-isolator comprises a diode disposed on the second floating circuit and a transistor disposed on the triple isolated circuit.

22. A method of increasing a creepage isolation distance in an electrical circuit, comprising:
optically coupling a ground circuit to a floating circuit with a first opto-isolator to electrically isolate the floating circuit from the ground circuit by a first creepage isolation distance; and
optically coupling an isolated circuit to the floating circuit with a second-opto isolator to electrically isolate the isolated circuit from the floating circuit by a second creepage isolation distance, and electrically connecting the first opto-isolator to the second opto-isolator in series to electrically isolate the isolated circuit from the ground circuit by a total creepage isolation distance equal to a combination of the first and second creepage isolation distances.

23. The method of claim 22 wherein the total creepage isolation distance is approximately 14 mm.

24. An electrical circuit, comprising:
a ground circuit;
a floating circuit optically coupled to the ground circuit, the floating circuit being electrically isolated from the ground circuit by a first creepage isolation distance; and
an isolated circuit comprising a first opto-isolator configured to optically couple a signal input of the isolated circuit to the floating circuit, the first opto-isolator comprising a diode disposed on the isolated circuit and a transistor disposed on the floating circuit, the isolated circuit being electrically isolated from the floating circuit by a second creepage isolation distance, the isolated circuit being electrically isolated from the ground circuit by a total creepage isolation distance equal to a combination of the first and second creepage isolation distances.

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